# CORE ANALYSIS COMBINING MT (TIPPER) AND DIELECTRIC SENSORS (SANS EC) IN EARTH AND SPACE


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## ABSTRACT

On terrestrial planets and moons of our solar system cores reveal details about a geological structure's formation, content, and history. The strategy for the search for life is focused first on finding water which serves as a universal solvent, and identifying the rocks which such solvent act upon to release the constituent salts, minerals, ferrites, and organic compounds and chemicals necessary for life. Dielectric spectroscopy measures the dielectric properties of a medium as a function of frequency. Reflection measurements in the frequency range from 300 kHz to 300 MHz were carried out using RF and microwave network analyzers interrogating SansEC Sensors placed on clean geological core samples. These were conducted to prove the concept feasibility of a new geology instrument useful in the field and laboratory. The results show that unique complex frequency spectra can be acquired for a variety of rock core samples. Using a combination of dielectric spectroscopy and computer simulation techniques the magnitude and phase information of the frequency spectra can be converted to dielectric spectra. These low-frequency dielectric properties of natural rock are unique, easily determined, and useful in characterizing geology.

TIPPER is an Electro-Magnetic Passive-Source Geophysical Method for Detecting and Mapping Geothermal Reservoirs and Mineral Resources This geophysical method uses distant lightning and solar wind activity as its energy source. The most interesting deflections are caused by the funneling of electrons into more electrically conductive areas like mineralized faults, water or geothermal reservoirs. We propose TIPPER to be used with SansEC for determining terrain/ocean chemistry, ocean depth, geomorphology of fracture structures, and other subsurface topography characteristics below the ice crust of Jovian moons. NASA envisions lander concepts for exploration of these extraterrestrial icy surfaces and the oceans beneath. One such concept would use a nuclear powered heated tip for melting through the ice sheath of Europa and inserting a down hole SansEC with TIPPER interface. NASA's Juno space probe already on the way to Jupiter as part of the Exploration New Frontiers Program and the planned Europa mission will conduct detailed reconnaissance of Jupiter's moon Europa and investigate whether the icy moon could harbor conditions suitable for life. It has already been observed that Jovian moons have auroras that may serve as naturally occurring active energy sources for a TIPPER instrument.



Keywords: Dielectric Spectroscopy, SansEC Sensors, TIPPER, Geophysical Mapping


ACRONYMS AND SYMBOLS

| | | |
|---|---|---|
| A | : | Absorption |
| R | : | Reflection |
| T | : | Transmission |
| $\varepsilon 0$ | : | free Space Permittivity |
| $\varepsilon r$ | : | relative Permittivity |
| $\mu 0$ | : | free Space Permeability |
| $\mu r$ | : | relative Permeability |
| C | : | equivalent Capacitance |
| f | : | Frequency |
| I0 | : | Current Amplitude |
| J(r) | : | current density |
| k | : | absorption coefficient |
| l | : | trace length |
| L | : | equivalent Inductance |
| $\rho(r)$ | : | charge density |
| $\omega$ | : | angular frequency |
| x | : | distance |

## INTRODUCTION

The objective of this effort is to research and develop radio frequency instrumentation and data processing techniques for planetary surface and subsurface spectroscopy. Building on current innovative research we anticipate near future and long-term development of a series of unique experimental ground-based, airborne, and space qualified light weight sounding instruments. These hardware systems and techniques will establish a baseline option of RF spectroscopic instruments for integration into future planetary science missions for Earth, Moon, and Mars in the near term as well as Jovian and Saturnian moons in the far term.

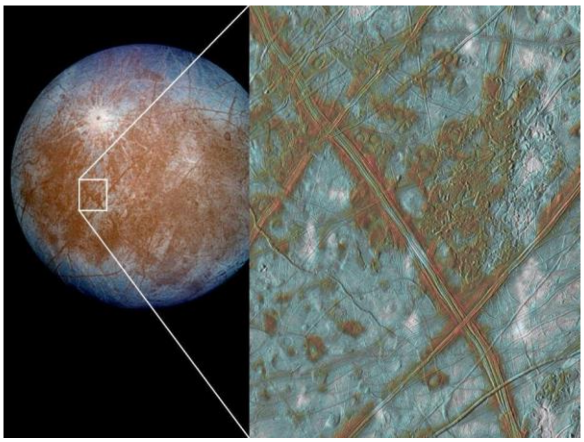


Fig. 1. Europa moon of Jupiter.

NASA will benefit from this initial activity by combining the skills and strengths of experts in Geology, Electromagnetic Sensors, Space Science, and Instrumentation. We will gain and advance the ability to integrate a series of ground based electromagnetic sensors with airborne electromagnetic sensors, and orbiting electromagnetic sensor platforms for the purpose of high resolution, broad area, multi-spectral scientific observations of surface and subsurface material composition of planetary bodies. This is to include science data on surface roughness, surface and subsurface chemistry <including organics>, material states (solid <including ice>, liquid, gaseous), dielectric characteristics of surface and subsurface geology, radar reflectivity, transmissivity, and emissivity for determining planetary albedo, atmospheric, climate, and other planetary properties. Such a wide range of science data from versatile electromagnetic sensors will enable and advance the Agency toward the longer term goal of exploration and understanding of planetary bodies within the solar system.

## DIELECTRIC SPECTROSCOPY

Dielectric reflectance spectroscopy is a maturing science that can be used to derive significant information about mineralogy with little or no sample preparation.[1] It may be used in applications when other methods would be too complicated, time consuming, or require destruction of precious samples. In this paper we propose a dielectric measurement system concept capable of being embedded in drilling tools and drill heads for use in down-hole operations on Earth and other terrestrial bodies in the solar system. The system can also be adopted for core sample analysis.

As an electromagnetic wave enters a mineral, a portion of the energy is reflected from grain surfaces, while some of the energy is absorbed, and the remainder of the energy passes through the grain structure. This follows the law of energy conservation as the total energy reflected, transmitted, and absorbed through a material must equal to one hundred percent of the incident electromagnetic wave.

$$R + T + A = 1$$

The electromagnetic energy that is reflected from grain surfaces or refracted through a particle are said to be scattered. Scattered energy may encounter another grain or be scattered away from the surface so that it may be detected and measured. For certain classes of minerals spectroscopy is an excellent tool. Among these classes are clay mineralogy, OH-bearing minerals, iron oxides and hydroxides, carbonates, sulfates, olivines and pyroxenes.[2]

All materials have a complex index of refraction:

$$\varepsilon = \varepsilon' - i\,\varepsilon'' \quad \text{electric permittivity}$$

$$\mu = \mu' - i\,\mu'' \quad \text{magnetic permeability}$$

where $\varepsilon$ is the complex index of refraction, and $\varepsilon'$ is the real part of the index or the energy storage term, $i = (-1)^{1/2}$, and $\varepsilon''$ is the imaginary part of the index of refraction or the energy loss factor.

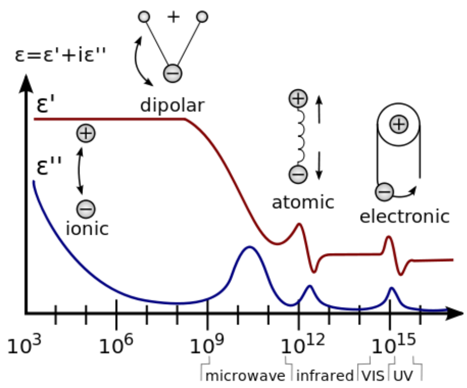



Fig. 2. Dielectric mechanisms.

The energy in an electromagnetic wave interacts with materials through either a relaxation or resonance process. The index of refraction is determined by chemical, thermal, mechanical, and electronic mechanisms in the core material as a function of frequency. At lower frequencies, electromagnetic excitation causes physical movement and relaxation of the ionic or polar molecules within a core sample material. At higher frequencies, electromagnetic excitation causes resonances of the atomic nucleus or the electron cloud surrounding the nucleus. Depending on the nature of the material, the dielectric mechanism, and the excitation frequency (f), energy is either stored or lost. [3] [4]

When energy enters an absorbing medium, it is absorbed according to Beers Law:

$$I = I_o e^{-kx}$$

Where, $I$ is the observed intensity, $I_o$ is the original intensity, k is an absorption coefficient and x is the distance traveled through the medium.

The absorption coefficient is related to the complex index of refraction by the equation:

$$k = 4 \pi f \varepsilon''$$

Electromagnetic energy can be absorbed in minerals by the processes described above. The variety of absorption processes and their wavelength dependence allows for the derivation of information about the chemistry of a mineral from reflected or emitted electromagnetic energy. This may be recorded as an energy spectra unique to the constituents of the core material sample. [5]

**THEORY OF SANSEC**

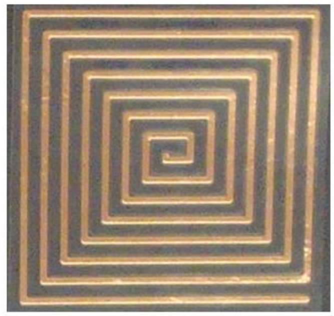


Fig. 3. A Generic Open-Circuit SansEC Sensor.

An open circuit resonant sensor has been developed for the purpose of dielectric spectroscopy of geological materials. The SansEC sensor is a planar resonant spiral or helix structure configured as an open circuit without direct (Sans) electrical connection (EC) to the material it is sensing or to the recording instrumentation. The sensor is composed of conductive material and formed in a manner such that the natural response of the geometry is to self-resonate when impinged upon by an external electro-magnetic field.

Electromagnetic resonance theory is well established for classical electromagnetic resonators such as resonant cavities, dielectric resonators, and LCR (inductive-capacitive-resistive) resonant circuits or structures. [6][7][8] The open-circuit resonator used as a sensor is a technology having unique features and applications. It is interrogated by a magnetic near field, self resonates at a specific fundamental frequency with useful harmonics, has a high power exchange efficiency, and responds to perturbations within its self-resonant field by detectable shifts in frequency, amplitude, phase, and resonance bandwidth. [9] This is

the foundation for using open-circuit resonators for sensing purposes.

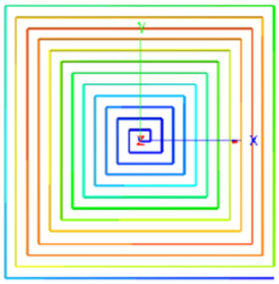


Fig. 4. Illustration of the Dominant Mode Current Distribution on an Open-Circuit Resonant Spiral (blue: lowest currents to red: highest currents)

The electro dynamic process of the open-circuit resonator is governed by Maxwell's equations with zero current boundary conditions at both ends of the resonant spiral. The free electrons carried by the conductor are uniformly distributed along the conductive trace when no external source is applied, but when driven by an oscillating electromagnetic field the induced electromotive force (EMF) pushes the electrons carried by the conductor into the resonant state where the electrons move back and forth along the conductive trace. The time-dependent current profile along the conductive trace has the form:

(1) $$I = I_0 cos(\frac{\pi x}{l}) e^{-i\omega t}$$

Where, $x \in [-l/2, l/2]$ is the parameterization coordinate along the length of the conductive trace; $l$ is the trace length; $I_0$ is the maximum current amplitude; and $\omega$ is the angular frequency with t as time. The induced current along the conductive trace has a cosine distribution with the peak magnitude at the middle part of the trace and zero values at both ends of the trace. During each oscillation cycle, the total current will reach the peak magnitude twice (in opposite directions) and at these moments the energy stored in the resonator is in the form of the magnetic field.

From the continuity equation, the charge density profile has the following form:

(2) $$q = q_0 sin(\frac{\pi x}{l}) e^{-i(\omega t + \frac{\pi}{2})}$$

Where, $q_0$ is the maximum charge density value. The charge is a sine distribution along the trace and creates the potential difference and consequently induces the electric field between the different localized segments of the trace. During each oscillation cycle, the electric field reaches its peak magnitude twice and at these moments the energy is stored in the electric field.

When resonating, the open-circuit sensor produces both electric and magnetic fields which occupy the space between the conductive traces and also penetrates into the space near the resonator. For the planar spiral sensor, the magnetic field and electric field will penetrate into the space beyond the planar surface of the sensor. This is an important feature for sensing purposes because it allows the sensor to measure the properties of the materials placed in close proximity.

Any physical quantity that affects the material's permittivity, permeability, or conductivity will affect the sensor's resonant parameters and therefore can be measured. Electric theory describes the LCR resonator by its lumped parameters of inductance L, capacitance C, and resistance R. For the self-resonant coil, the equivalent lumped parameters can be calculated based on the distributed parameters, as shown in equation (3) and equation (4), where $\mu_0$ is the free space permeability, $\mu_r$ is the relative permeability, $\varepsilon_0$ is the free space permittivity, $\varepsilon_r$ is the relative permittivity, and $\mathbf{J}(\mathbf{r})$ and $\rho(\mathbf{r})$ are the current and charge density functions along the conductive trace. [9]

(3) $$L = \frac{\mu_0 \mu_r}{4\pi |I_0|^2} \iint \frac{\mathbf{J}(\mathbf{r}) \cdot \mathbf{J}(\mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|} \mathrm{d}\mathbf{r} \mathrm{d}\mathbf{r}'$$

(4) $$C^{-1} = \frac{1}{4\pi \varepsilon_0 \varepsilon_r |q_0|^2} \iint \frac{\rho(\mathbf{r}) \cdot \rho(\mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|} \mathrm{d}\mathbf{r} \mathrm{d}\mathbf{r}'$$

However, the current and charge density functions are not measurable in actual experiments. Therefore, the equivalent inductance and capacitance values of a self-resonant coil are the calculated values and are used

only for principle analysis. From equation (3) and equation (4), it can be clearly seen the dependency of inductance and capacitance upon the material's relative permeability $\mu_r$ and relative permittivity $\varepsilon_r$. If the material in the electric and magnetic field changes its permeability and/or permittivity, the resonator equivalent LC value will change correspondingly, so will the resonance parameters. It is notable that equation (3) and equation (4) are for the cases where the resonant sensor trace is totally embedded in the material having isotropic properties. For most actual applications, for example, the material is put on one side of the resonant sensor, the dependency function between the sensor parameters and the material properties is not obvious and needs to be characterized and calibrated by experiments or computational methods. [10]

## IN THE LABORATORY

The laboratory is equipped with measurement instrumentation, tools, hardware, material resources, and various means of fabrication. The primary instruments used in experimental SansEC sensor research are radio frequency and microwave network analyzers. The laboratory has three network analyzers that together cover frequency ranges from 10 kHz to 50 GHz. Figure 5 illustrates an Agilent E8364C Performance Network Analyzer (PNA) system interrogating a SansEC sensor. The PNA is a vector network analyzer capable of generating and measuring the frequency, magnitude, and phase of an electromagnetic wave. It is shown here connected to a near-field square loop antenna. [11] The loop antenna is used to illuminate or "ping" the SansEC sensor with a broadband frequency sweep from the network analyzer and then "listen" or receive the return response from the SansEC.

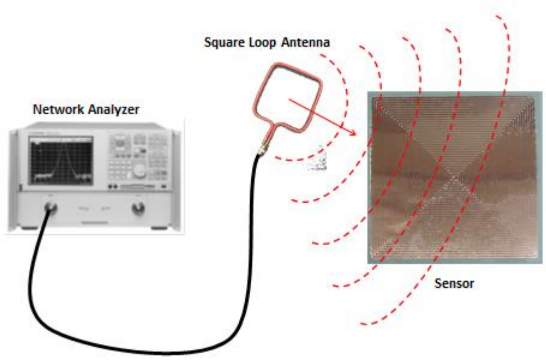
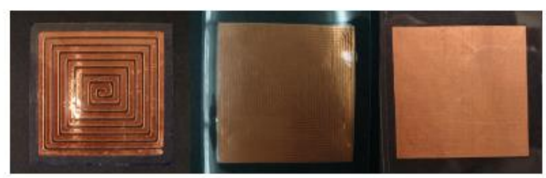



Fig. 5. RF Network Analyzer connected to Loop Antenna illuminating a SansEC Sensor.

The transmitted energy from the loop antenna excites resonant modes in the sensor. The resonant response frequency is usually comprised of a fundamental and associated harmonics related to the sensor geometry. The sensor is coupled to the loop antenna through the magnetic near field and the induced current (total current) in the sensor will have the maximum magnitude near its resonant frequency. At resonant state, the energy radiation of the sensor reaches its maximum value and so does the energy transferred to heat by the intrinsic resistance of the sensor trace. The resonant frequency of the sensor is indicated by the minimum amplitude of the reflection coefficient at the terminals of the loop antenna. The response is measured by the network analyzer as a return loss scattering parameter. The return loss S-parameter $S_{11}$ is the reflection coefficient and is displayed on the network analyzer as a distinct amplitude resonance signature as a function of frequency.

## SANSEC SPECTROMETER

The SansEC reflectance spectrometer is an arrangement of an array of multiple open circuit planar resonant spiral sensors each operating at a unique fundamental frequency.



Sensor 1 Sensor 2 Sensor 3

Fig. 6. SansEC Sensors of unique frequencies.

The array is intended to either be brought into contact with an extracted geologic core sample or to be brought into contact with the material surface of the wall of a down-hole bore hole. The way in which the sensor array is brought into contact with the test sample relies on getting electromagnetic waves to travel from the SansEC Sensors into the rock sample. As the incident electromagnetic energy couples into the material medium changes occur in amplitude and phase that are directly related to the electric permittivity, magnetic permeability, and conductivity of the core sample or mineral formation. Because there is a large contrast between the permittivity of rock and the baseline permittivity of Free Space, the spectrometer tool easily makes a direct measurement of the reflection properties of the rock.

Fig. 7. Proof-of-Concept Sensor on geologic core sample.

Depending on the nature of the rock, the permittivity, permeability, and conductivity differ for different frequencies of the incident electromagnetic waves. For the proof-of-concept tests, sensor 1, sensor 2, and sensor 3 were placed in the exact same position on the flat smooth surface of the semi-cylindrical geologic core sample simulating a linear array of sensors scanning across the sample. This allowed for multiple interrogation frequencies to couple into the rock sample. The scattering of multi-frequency electromagnetic energy from grain surfaces or refracted through mineral particulates and layers causes dielectric dispersion. Dispersion allows for the taking in account of the molecular material properties that constitute a mineral formation. With multiple frequency measurements the phenomena of dielectric dispersion may be observed as scattering parameter spectra representative of the unique characteristics of the test sample and relevant to the geological identification of the core materials and formations from which the sample was extracted.

**Response Characteristics of Geologic Cores**

Six unique core samples similar in size and shape to figure 7 were measured using the three sensor multi-frequency SansEC spectrometer technique. All six experiments produced repeatable and promising results. Two reflection spectra for two different core samples are shown in figures 8 and 9 below.

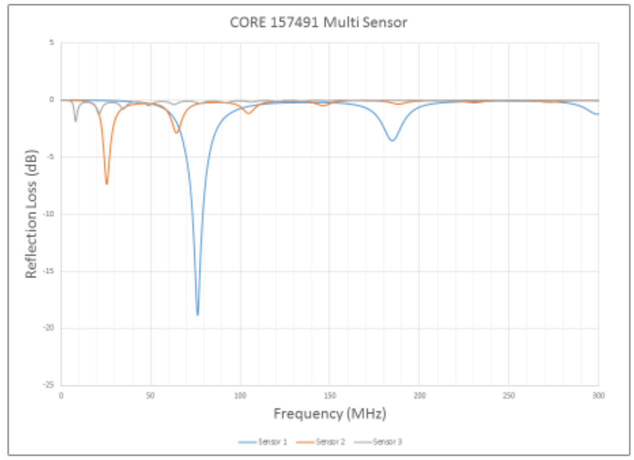



Fig. 8. S-Parameter plot depicting Reflection Resonances for Geologic Core Sample 157491.

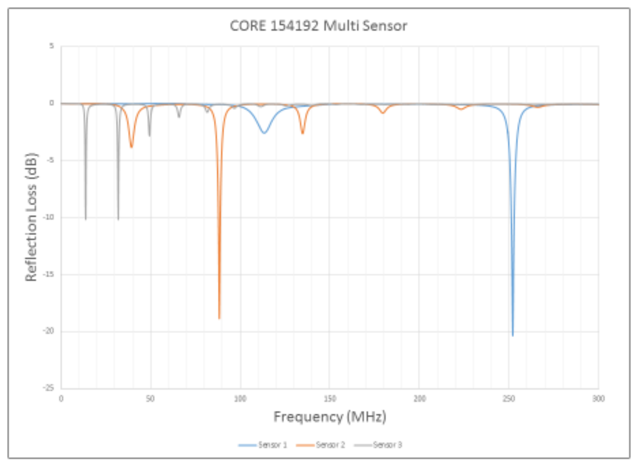



Fig. 9. S-Parameter plot depicting Reflection Resonances for Geologic Core Sample 154192.

The initial laboratory experiments proved that a SansEC sensor placed on a geological material surface is capable of determining physical characteristics and qualities about the material upon which it is placed. [7][8][9][10][11] The detection of the differences in frequency and amplitude of the induced currents within a material substrate offers a means of identifying geological specimens.

## EXTENDED SANSEC SPECTROMETER

An array of SansEC sensors of unique frequencies may also be arranged on the surface of a bore tool. If arranged in a linear fashion along the longitudinal axis of a cylindrical penetrator, the sensors could sense the dielectric reflectance profile of the wall surface as a function of depth as the tool slid down the bore hole. The illustration in figure 7 depicts such a device with seven unique frequency SansEC sensors attached to form the multi-frequency spectrometer array.

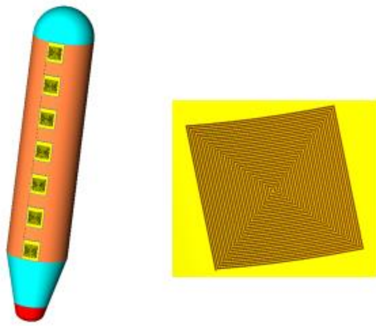


Fig. 10. Illustration cylindrical bore-hole penetrator.

Planetary Thermal Penetrators are methods of drilling using a hot drill tip to melt ice, rather than cut through it. These devices have been tested in Antarctica.

Fig. 11. Cylindrical thermal melt probe penetrator.

Many areas of our solar system are ideal candidates for thermal drill exploration. A thermal melting probe could penetrate ice in remote Earth locations, Mars, Europa or other equally remote exploration targets. Shown below in figure 12 is a conceptual rendering of a NASA thermal melt probe about to begin a journey deep through the ice of Jupiter’s moon Europa on a quest to penetrate through to the hidden liquid ocean beneath.

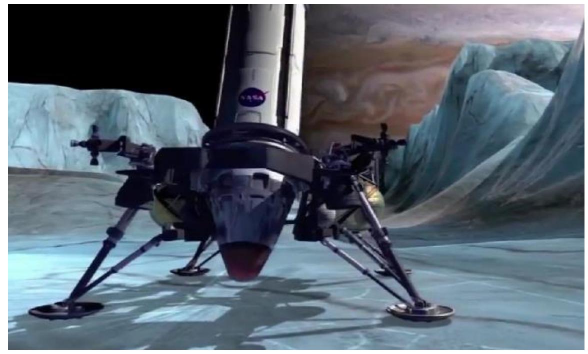


Fig. 12. Conceptual thermal melt probe lander

A SansEC spectrometer would be implemented and integrated into the exploration probe in a fashion similar to that illustrated in figure 10 as an instrument for acquiring the dielectric geological profile of the formations between the surface and the sub-surface ocean.

## COMPUTATIONAL EXPERIMENTS

Computational Electromagnetic Modeling (CEM) and simulation is a very useful research and development tool. By using iteration and feedback to model physical hardware and then validate the CEM against that physical hardware by means of experimental measurements, a better and more economical hardware product can be realized. Simultaneously a more robust design tool is developed that will enhance the next stage of design complexity. As understanding and confidence in the computational model and the experimental measurement increases, the ability to integrate sub-elements into larger systems occurs. In this manner we undertake steps in designing, integrating, and understanding SansEC resonant sensors both as computational models and physical hardware components. We use **FEKO**, "**FE**ldberechnung für **K**örper mit beliebiger **O**berfläche" or "Field Calculations for Bodies with Arbitrary Surface", a commercial computational electromagnetic software package to model our open-circuit resonant sensors. [11] [12]

The modeling effort enables an intuitive understanding of the electromagnetic field penetration interactions with simulated geological formations and core samples. The insights gained are used to inform the experimental design and testing on actual geological core samples.

## THE ROLE OF TIPPER

The concept of the mathematical relationship of the vertical to horizontal field, subsequently being named 'Tipper' by Keeva Vozoff, has been around and conceptually well understood since the early 60's. However, most of the academic work was not blessed with large numbers of experimental data sites to work with; and the focus was not really directed toward interpretation experience. Dr. Vozoff was one of the early EM geophysics academics and was involved in early 3D numerical modeling work applied to Magneto Telluric (MT). There were others at MIT that were interested in MT, and was involved in some commercial attempts and collaborations, past students of Dr. Ted Madden, including Dr. Charlie Swift. As academics, the group lacked the vital ingredient of deployment and the special techniques required by sound field practice and data acquisition of MT data. They were familiar with the Tensor mathematics related to MT response and EM modeling techniques, but those early days were prior to the availability of computer capability and served as a principal limiting issue.

It was well after the Hz to horizontal H relationship was recognized that Keeva came up the name "tipper". It needed a name, and, as this seemed somewhat descriptive, it stuck. That is to say, Keeva was not the one who actually discovered the Tipper concept. Charlie Swift, at MIT was the first to publish (in his doctoral thesis) the full Tensor mathematics describing the MT response, including Hz to horizontal H. There are, to be found, several rather difficult and possibly, more cumbersome mathematical means to express the field responses, but the Tensor expression, together with relations for coordinate rotation, proved to be a substantial contribution to the study and treatment of the MT response. This did not reveal any new basic knowledge of the related physics and EM field theory, as being now studied by Dr. Francis Bostick, and his team. This, however, did provide some new and useful means to view and assess the MT data. Subsequently, work by Dr. Darrell Word, drew upon the Charlie Swift Tensor treatment, to examine some of the Tensor response properties, including coordinate rotation behavior and added some useful implications about the nature of the target structure. In particular, the elliptical properties of the loci of the Tipper and Impedance complex components. This permits interesting and useful general properties of the target structure (especially strike and dip, among other items). There are special theoretical structural anomalies and symmetries that yield useful insights into revealing the cause of a measured response, especially the nature of the dimensionality. Such behavior as the ellipticity and elliptical orientation for TIPPER, certainly provide for innovative intuitive results of the interpretation by the current iteration of TIPPER by today's TDD International team, headed by Byron Arnason.

Fig. 13. Byron Arnason and the revolutionary tripod-mounted ROVER that enables the Hz high production detection for long distance TIPPER surveys.

The work provided by Dr. Darrell Word, however, produced several survey sites employing full 5 component measurements, including Tipper and related parameters. There were of course attempts to associate the Tipper behavior with the geology, with fairly interesting and satisfying results. Then through the thousands of commercial MT sites measured by an early user of TIPPER, similar techniques were employed, always computing and making some use of TIPPER in these interpretations. In all cases, this experience covered essentially the entire frequency band (except that the high end was usually no more than 10 Hz). There was much use and experience with TIPPER to follow, and an essential point here, is that In most all cases, the site density did not tend to be as high as for the higher frequency band use, as needed for mining exploration, etc.; and, the availability of good, useful 3D modeling capability did not exist; and, of course, the main focus for the MT work was to interpret and map the conductivity obtained from the impedance function. TIPPER was then mostly used (in a more crude hand-waving manner) to help ponder the general shape of the conductivity structure. Although TIPPER was recognized and treated as an essential component of the observable MT response at each measuring site, it was not used by itself as an independent survey tool.

What is important here is that the current iteration of TIPPER, provided and pioneered by our group, notably by our Byron Arnason (one of the original patent co-authors) brought to us an impressive innovation and

roving Hz coil methodology, with the clever pendulum mount and rapid deployment and data acquisition; and eventually, an enormous quantity of experience and experimental data. There are now better 3D modeling resources, but the biggest improvement in TIPPER surveying has arisen from our new refined system and the rather enormous experience in recording and observing and interpreting TIPPER data in a geologic environment.

New work has proven TIPPER to now provide a wealth of useful information about the strike and dip orientation of the anomaly and the nature and aspects of its dimensionality. Some useful illustrations can convey this. The inherent skin effect in the conductive medium provides useful insight about relative depth and spatial orientations, although values of related conductivity (measurements or estimated) are needed for more refined depth determination.

Although the 'new work' is important and substantial, it did not amount to recognition of how to identify strike and dip information and the nature of dimensionality. The properties of the skin effect relationship to depth is not a new idea in regard to TIPPER. One new and highly important point, however is that our Byron Arnason has to gained and effectively used experimental insights and intuitions toward applying the said information in the real world exploration problems as have been experienced. This has been accomplished via the combination of field practice, EM knowledge along with familiarity with local and regional geology and exploration techniques.

Estimation of strike and dip (and depth) thereto, as well as the qualitative degree of three-dimensionality are properties that indeed were almost always employed by others; however, it was obvious that more scientific and practical applications were required, especially with respect to depiction for 3D cases. This required greater focus, experience and better resources. In general, as to 3D geometry, precise and confident interpretations require some means of quantitatively modeling the problem. Better resolution and results are becoming reality.

Finally, it is important to recognize the benefit of an independent Reference H station to observe the surface horizontal H field (primary field) in an independent noise environment. This is not a fundamental essential to the TIPPER method, but it is usually of substantial benefit in reduction of measurement noise. This technique, first developed and used commercially by Geotronics Corporation, is done in the data processing via cross power spectrum stacking between the survey data and the Reference site data, depending on the notion that the desired H signals are precisely correlated and the respective noises are independent.

TDD’s current methodology uses this approach effectively.

**FUTURE DEVELOPMENT**

NASA has long been interested in geology for planetary science. Early Lunar Astronauts were trained in geology techniques and one of the last Lunar Astronauts, Harrison Schmitt, was a professional geologists. All Apollo astronauts went through geology field training to prepare them for collecting rock samples on the moon

Fig. 14. Astronaut Charlie Duke during Apollo 16 using a bore hole tool for vertical profile samples of the lunar regolith.

The lunar samples and data returned to Earth in the 1960s and 70’s revealed that the moon has a complex geology. Still, a substantial portion of the lunar surface has not been explored, and a number of geological questions remain unanswered. Today, data from lunar satellite probe missions continue to add to our understanding of the moon’s mineralogy, geomorphology, chemical composition, and history. Each modern mission uses its own unique suite of instruments to explore the moon. From these combined explorations lunar scientists are finding water, oxygen, and a wealth of interesting compounds embedded in the lunar surface and waiting to be explored by future sampling missions. TIPPER and SansEC based instruments could play a role in the future explorations of Earth’s moon.

On Mars, most of our current knowledge about the geology of the surface and sub-surface comes from images taken by orbiting spacecraft. Interesting geological features such as avalanches, caves, and suspected lava tubes have been spotted from orbit by high resolution imaging cameras. Inverted relief

features in the shape of streams are evidence of water having flowed on the Martian surface in the distant past. Researchers propose that some of the layers on Mars are caused by groundwater rising to the surface in many places. More excitingly there is evidence from recent orbital observations that water in the liquid state is currently flowing in sub surface channels on Mars.

On the ground rovers are not in the immediate vicinity to validate observations hinting at sub-surface liquid water flow. However, the Curiosity Rover has used its drill tool to bore holes and acquire rock core sample from inside rock structures for testing of the chemical constituents that makeup particular rocks.

Fig. 15. Core sample on Mars.

It is not difficult to imagine SansEC sensors integrated into the drills of ground based explores on mars. We can even imagine SansEC spectroscopy sensors incorporated into the wheels of future ground based rovers constantly acquiring a trail of RF spectroscopic data as the vehicle rolls along the varying surface of the planet.

The latest news from our robotic explores in the outer solar system is confirming that several moons of Jupiter and Saturn have compelling geological features and formations that make convincing cases to instrument the next scout and flagship missions with electromagnetic sensors capable of detecting, characterizing, and mapping, sub-surface geomorphologies. Magnetometer data from the Galileo space probe provides evidence of an induced dipole magnetic field consistent with the presence of a salty ocean on Europa. Jupiter's magnetic field is inclined to its rotation axis, and the four Galilean satellites Callisto, Europa, Io, and Ganymede experience a time-varying magnetic field. Europa responds to this field as a nearly perfectly conducting sphere, generating electrical currents that create a magnetic field that opposes and cancels the time-varying component in its interior. This data along with, gravity data, and observed surface features strongly suggest that Europa has an ocean at least several kilometers thick beneath its ice shell and that the ocean contains conductive electrolytes such as sulfates or alkali salts. A world that shows strong evidence for an ocean of liquid water beneath its icy crust could host conditions favorable for life. [13][14][15]

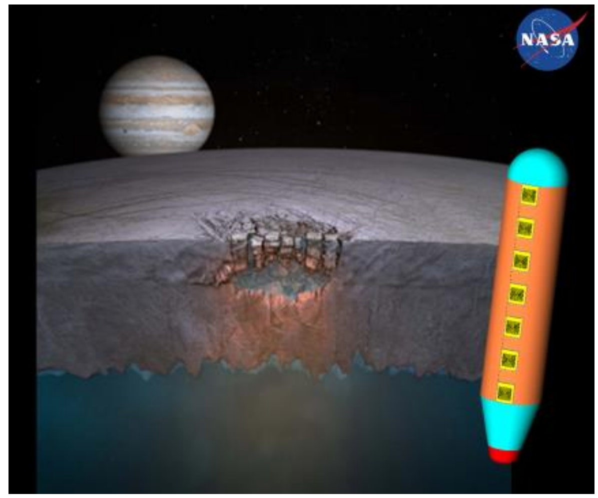



Fig. 16. Conceptualization of Europa's subsurface ocean and geomorphological features.

## CONCLUSIONS

The SansEC sensor and TIPPER represent our belief that the combination of these innovations could enhance science data returns of future exploration space missions. [16] These dedicated electromagnetic sensors offer baseline components that could form the architecture of instrument systems to acquire better data and knowledge of what lies beneath the surfaces of terrestrial and extra-terrestrial terrains throughout the solar system.

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